I. INTRODUCTION

When a submarine is at periscope depth beneath a seaway, several exciting forces and moments are encountered. These include first-order oscillatory motions at the prevailing wave frequencies and second-order drifting motions at very low frequencies well outside the wave spectrum of the seaway. These are referred to as the free surface suction forces and moments. In practice these low frequency motions are difficult to control and may give rise to unsatisfactory depth keeping. Standard ways of computing free surface effects rely on combinations of potential flow and semi-empirical coefficient based models. Rankine type sources are distributed along the hull of the ship, which satisfy the free surface boundary condition. Source strength can be computed by satisfying the exact body boundary condition, that no fluid can pass through the hull surface. Discretization of the hull form into a finite set of Hess-Smith type quadrilateral panels allows formulation of algebraic system of equations to be solved for the unknown singularity strengths. [Ref. 1] Combination of forces and moments generated in this way with deep water force predictions can then be utilized to simulate the motion of the boat under waves.

Although such suction forces and moments are difficult to predict, they are slowly varying in time and as a result they can be controlled by either the operators or automatic control systems. Techniques of disturbance estimation and compensation can be employed in order to allow satisfactory real-time estimation of unknown disturbances from depth, pitch angle, and pitch rate measurements [Ref. 2]. In contrast to these second-order forces, first-order forces cannot be actively controlled in practice since they occur at very high frequencies (in the order of magnitude of a few seconds) which are normally outside the range of hardware response times. Therefore, it is essential that we have a clear understanding of the effects of first-order excitation on boat missions in order to maximize its window of operations. This approach will identify parameter regions where operations may be carried out with higher degrees of confidence of success and with better opportunities for active control. In order to achieve this first we need to have a computational tool which will allow us to determine vehicle motions in the vicinity of a free surface in deep and shallow water. In this work we utilize a strip theory seakeeping prediction program based on the work by Beck and Troesch [Ref. 3].

Accurate submarine maneuvering predictions are essential for operation, to provide optimal and safe submerged operating envelopes. Relative vertical motion is one of the most important response elements that appear to be the most crucial to the submarine operators for successful completion of a mission near a free surface. To decide whether the submarine could complete her mission successfully or not we need to adopt a number of criteria each pertaining to different operational hazards. These criteria can be broadly divided into two major categories, subtle and catastrophic failures. In this study we consider two criteria. One of them is periscope submergence, which is a subtle failure and the other is sail broaching, which is a catastrophic failure.

Subtle failures refer to events which will occur in all types of periscope depth operations, i.e., propeller emergence, mast emergence, periscope submergence. Single occurrence of these events does not constitute failure of operations. However, their frequency imposes operability limits for a certain sea state. Periscope submergence impairs visual information. The dominant criterion is the number of occurrences per unit time.

Catastrophic failures will probably result in either cancel of operations, failure to complete mission or submarine detection, i.e., broaching, loss of depth control deep. Broaching the sail is defined here as any portion of the sail breaking the surface. It is assumed that submarine detection will occur with probability of one each time a broaching occurs.

In shallow water operations, we employ an additional criterion in addition to the two above. This corresponds to the event of vehicle collision with the sea-bed and is determined statistically based on the absolute vertical motion of either the bow or the stern of the vehicle and its clearance from the sea-bed. Combination of all of the above criteria provides a quantifiable measure of vehicle operability within a certain range of sea-states and directions.

Chapter 2 of this thesis describes the mathematical foundation for the problem. Chapter 3 presents results for the operability index of a vehicle for periscope submergence and sail broaching criteria for different sea-states and wave heading angles and deep water operations. In Chapter 4 the operability index of the vehicle is presented for periscope submergence, sail broaching, and collision criteria for shallow water operations. Finally, conclusions from this work and recommendations for further research are outlined in Chapter 5.